

The University of Chicago

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BROME GRASS UNDER CERTAIN
ENVIRONMENTAL CONDITIONS

A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE BIOLOGICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

DEPARTMENT OF BOTANY

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Reprinted from
THE BOTANICAL GAZETTE
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FLOWERING OF SMOOTH BROME GRASS UNDER CERTAIN ENVIRONMENTAL CONDITIONS¹

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY 588

HAROLD J. F. GALL

Introduction

The increasing importance of smooth brome grass (*Bromus inermis* Leyss.) as a forage crop and in reseeding denuded ranges has led to the necessity for more accurate selection of types adapted to a wide range of latitudes and climatic conditions and to a program of developing improved strains. A knowledge of the conditions necessary for vigorous production of panicles and the setting and maturing of seed, both in the field and under greenhouse conditions, is needed for the efficient carrying-out of such work. In this study a series of clones of brome grass, representing various strains, was examined with regard to these requirements, with especial attention to the production of viable seed, and to determine to some extent the factors involved in the initiation of floral primordia and their subsequent development. The experiments were carried on at the University of Chicago during 1946 and 1947.

The wide range of variation within the species has been recognized for many years. WALDRON (13), in a study of several thousand seedlings of brome grass in North Dakota, found much variation in physiological and morphological characters. He noted a range from a strongly "fertilclinous" condition to a strongly "sterilclinous" one and a similar range in tillering habits. NEWELL and KEIM (7) have reviewed the history of the species

in the United States. In field trials at Lincoln, Nebraska, they noted distinct differences between plants originating from northern sources and those from Nebraska and Kansas in vegetative growth and panicle production. Wide differences among strains in their adaptation to this region were apparent. EVANS and WILSIE (3), in greenhouse experiments, found that three clones—early, midseason, and late-maturing, respectively—responded differently to changes in daylength, temperature, and level of fertility. WATKINS (14), using seed of a commercial strain from Saskatchewan, concluded that brome grass was an indeterminate species photoperiodically, in the sense of GARNER (5), in that most fertile shoots were produced on natural daylength. ALLARD and EVANS (1), however, after finding no flowering on photoperiods of 10–13 hours and more vigorous flowering with longer photoperiods beyond 13 hours, assigned the species to the long-day class.

Material and methods

To insure genetic uniformity clonal material was used in all experiments. The clones available at the time of experimentation provided a range of morphological habit and place of origin.² OM-1 traces back to a plant selected for selfing in a bulk lot of the Canadian variety, Parkland. OM-2 goes back to a Nebraska

¹ This work was aided in part by a grant from the Dr. Wallace C. and Clara A. Abbott Memorial Fund of the University of Chicago.

² Material of all clones and data on their origin were supplied by Dr. ETLAR L. NIELSEN, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, United States Department of Agriculture.

strain, B-4. OM-3 is a selfed line out of PI 115331 from Leningrad, Russia. Cl 3 represents the isolation of the better plants from PI 115334 from Leningrad. Cl 8 is an isolation from FC 22435 (original source not known at the time of writing). Cl 9 is an isolation from PI 101647, received from Manchuria. The origin of Cl 19 and 65 is not known. Cl 23, 27, 31, and 84 are all selected plants from bulk lots of Parkland seed. 914-1 is from the first inbred generation of a plant of the Parkland variety. The plants used represent the species over a latitudinal range of approximately 20°.

Equal divisions of each clone were made from plants previously established in the experimental garden and were planted in 8-inch unglazed clay pots. The soil used was a heavy clay loam of prairie origin, lightened with a mixture of sand and fine gravel. It undoubtedly contained a supply of mineral nutrients adequate to prevent deficiencies during the course of the experiments. Ten days after potting, all plants had shown vigorous growth. They were watered as often as was necessary to keep the soil constantly moist.

Supplementary light in experiments I and II was supplied for all except two series by banks of twelve 40-watt fluorescent lamps of the "Daylight" type mounted $2\frac{1}{2}$ inches apart on a white-enameled reflecting board. These gave a light intensity of about 800 foot-candles at a distance of 10 inches below. Lights were raised periodically as the plants grew. Pots containing plants of slower growth were elevated individually to keep the general foliage level of a series fairly uniform.

In experiment I in 1946, two of the series, designated 17M and 15M, were given supplementary light from 200-watt incandescent-filament lamps mounted in

individual reflectors. Light intensity at plant level was about 150 foot-candles. These two series were placed on movable trucks and received natural daylight for 9 hours in the open greenhouse and artificial light for 8 and 6 hours, respectively, after being moved into ventilated light-proof sheds.

Three of the series in 1946 were grown on a greenhouse bench with the banks of fluorescent lamps suspended above them, and the lights were kept burning throughout the light period. Black cloths, coated white on the inside surface, were hung from each reflector to inclose the plants during the dark period. These were opened on the side to the south during the day, and on sunny days the reflectors and cloths were raised to allow maximum and equal illumination of all plants. Temperatures inside the cloths were found to vary considerably, long photoperiods resulting in higher temperatures; consequently, later experiments were run in the sheds or in the open greenhouse without the inclosing cloths.

Flowering response was evaluated by noting the first exertion of the inflorescence from the ensheathing leaves and by the later development and vigor of panicles. In some cases the status of the apical meristem in respect to vegetative or reproductive condition was determined by dissection and microscopic examination. Vegetative response was evaluated mainly by maximum height of plants, number of new tillers produced, number of tillers showing elongation, and dry weights of roots and tops at final harvest.

Experimentation

EXPERIMENT I.—Twelve dormant plants were brought into the greenhouse on January 10, 1946, and on January 11 small pieces of rhizomes, fairly uniform

as to size and condition of growing points, were planted in individual pots. They rapidly resumed growth, and on January 22 one pot of each clone was placed under each of six treatments. Three photoperiods—17, 15, and 13 hours—were used with fluorescent light, and two photoperiods—17 and 15 hours—with incandescent-filament light. A series (*N*) was also run on natural day-length and light intensity.

Air temperatures given in table 1 represent averages of measurements over the course of the experiment, which was

TABLE 1

AIR TEMPERATURE (IN ° F.) AT PLANT LEVEL. EXPERIMENT I

Series	Av. min.	Av. max.	Range	Mean
17-hour.....	68.6	85.3	69-90	77.0
15.....	66.5	84.8	62-89	75.7
13.....	66.2	82.3	62-90	74.3
17M.....	63.3	75.2	55-79	69.3
15M.....	58.3	69.8	51-74	64.1
N.....	63.7	70.8	58-90	67.3

terminated, except for the *N* series, on April 18, 1946.

Flowering response, as based on the date on which the first inflorescence was exerted in each plant, is shown in table 2. Anthesis followed in approximately 14 days in all cases, with the exception of the weak or sterile panicles. Six of the twelve clones flowered on 17-hour photoperiod; four of these six flowered also on 15-hour photoperiod, though less vigorously and from 5 to 26 days later. Five of the six flowered also on 13-hour photoperiod, in addition to two clones that flowered only on this light period. Inflorescences on 13-hour plants were at best of only fair vigor in comparison with 17-hour plants. Three of the controls on natural daylength flowered, though poorly and from 34 to 44 days later than on 17-hour photoperiod.

Differences in vigor of growth and flowering between the 17-hour series under fluorescent and under incandescent-filament light were marked. Five plants of the latter series flowered, producing rather poor panicles from 4 to 21 days later than the plants of the same clones under the higher light intensity of the fluorescent lamps. The 15M series was inferior in all respects to any of the

TABLE 2

NUMBER OF DAYS UNTIL FLOWERING AFTER BEGINNING OF PHOTOPERIODIC TREATMENTS ON JANUARY 22

CLONE	SERIES					
	17	15	13	N	17M	15M
OM- 1.....	.....	.....	68	.....	.....	.....
2.....	.....	.....	.....	.....	.....	.....
3.....	23	28	37*	.....	33*	47*
Cl 3.....	24	.....	30	68*	28	46*
8.....	.....	.....	.....	.....	.....	.....
9.....	17	33	.....	.....	38	.....
19.....	28	.....	54	.....	38	.....
23.....	.....	.....	56*	.....	.....	.....
27.....	22	48*	38*	56*	28*	46*
31.....	.....	.....	.....	.....	.....	.....
65.....	21	28	28*	56*	.....	.....
84.....	.....	.....	.....	.....	.....	.....

* Poor and sterile panicle.

others. Three plants exerted inflorescences in 46 days, but they were of insufficient vigor to reach anthesis. It is emphasized that the 17M and 15M series received only natural daylight for 9 hours of the photoperiod, while the series under fluorescent light received artificial light continuously during the photoperiod. Considering the many very cloudy days of the Chicago winter as well as the relatively low intensity of the supplementary incandescent-filament light, the total illumination of the M series was undoubtedly below the minimum required for normal growth. The lower range of temperatures (table 1) to which these plants

were exposed during the period of experimentation was probably another factor contributory to their lack of vigor.

No seed was matured by any plants, although the panicles produced by the 17-hour plants under fluorescent light appeared to be vigorous and the pollen under microscopic examination to be normal. It was thought probable that the high temperatures resulting from inclosing the plants and lights with heavy lightproof cloth were responsible for this failure. Further experiments were modified to provide better control of this factor.

In vegetative response there were marked differences among treatments under fluorescent lights. The twelve clones, at the time of harvest on April 18, had produced totals of 74, 56, and 26 elongated tillers on 17-, 15-, and 13-hour photoperiods, respectively. Numbers of unelongated tillers were inversely correlated with photoperiod, with totals of 97, 146, and 218. Total numbers of tillers—171, 202, 244—were also inversely correlated with length of the light period. Maximum height was measured from the soil surface to the tip of the longest leaf or inflorescence and was directly correlated with length of photoperiod for most clones, the averages being 66.6, 55.6, and 50.0 cm., respectively. These differences were clearly reflected in the general aspect of the plants (figs. 1-3).

Comparable data for the 17M and 15M series, respectively, are: elongated tillers, 44 and 15; unelongated tillers, 37 and 121; total tillers, 81 and 136. They show clearly the limited growth made under low light intensity and average low temperature in these series in contrast with those under fluorescent lights, and also the effect of the longer photoperiod in inducing elongation of tillers.

Total numbers of rhizomes for the

twelve clones showed no apparent influence of photoperiod but a strong influence of light intensity and temperature. The 17-, 15-, and 13-hour plants produced a total of 40, 39, and 41 rhizomes, respectively, while the 17M and 15M series produced only 5 and 6.

EXPERIMENT II.—In this experiment plants were brought into the greenhouse from the garden at two different times, on August 31, 1946, and again on December 27, to test the effect of exposure to low temperatures and of long establishment in the pots on floral initiation and emergence. Six of the clones used in experiment I were used. Of these, Cl 9 and Cl 27 had flowered readily on long photoperiod, OM-1 and Cl 23 had flowered only on a short light period, and OM-2 and Cl 84 had not flowered on any treatment (table 2). Four divisions of each were made on each date. Large pieces of entire plants were used for each division rather than single rhizomes.

After potting, the August plants were trimmed of dead parts and old sterile culms but otherwise left intact. They were kept on natural daylength in the greenhouse until differential treatment was begun on January 7, 1947. During this period they were given several hours of artificial light on very cloudy days to prevent too great loss of vigor; this was supplied without extending the photoperiod. Growth during September to January was limited, and most of the plants had declined perceptibly in vigor by the time treatments were begun. Food reserves for further growth were thus probably low, and the response of these plants to photoperiodic treatments in contrast to that of the December plants may have been conditioned by this fact as well as by lack of pre-chilling.

On January 7, two series, each including August and December plants, were



FIGS. 1-3.—Clonal divisions of smooth brome grass grown from single rhizomes brought into greenhouse on January 10, 1946. After January 21 they were subjected to (left to right): Chicago natural daylength and light intensity (series *N*); 17 hours of relatively low light intensity (series 17M); 13, 15, and 17 hours of relatively high light intensity (fluorescent light). Fig. 1, Cl 84; fig. 2, OM-3; fig. 3, Cl 27. (Photographed April 16, 1946.)

placed on movable trucks in lightproof sheds. Banks of twelve 40-watt fluorescent lamps as described above were used to provide 18- and 13-hour photoperiods. On sunny days the trucks were moved out of the sheds to provide maximum light intensity throughout the light period. In addition to a series (*N*) on natural daylength and light intensity in another greenhouse room, an additional 18-hour series (18C) was run under

TABLE 3
AIR TEMPERATURES (IN ° F.) AT PLANT
LEVEL. EXPERIMENT II

Series	Av. min.	Av. max.	Range	Mean
18-hour. . . .	67.0	74.3	63-82	70.7
18C.	66.8	74.3	57-87	70.6
13.	63.8	72.6	55-79	68.2
<i>N</i>	66.6	74.1	59-88	70.4

fluorescent lights in still another greenhouse room as a check on conditions in the sheds.

Temperature data (table 3) indicate a much better control of this factor than in 1946.

Flowering data are given in table 4. Of the plants brought in on December 27, all clones flowered on 18-hour photoperiod within 26 days. Anthesis followed about 2 weeks later. There was good agreement between the 18 and 18C series. One clone, Cl 9, flowered on 13-hour photoperiod, 20 days after first flowering on long photoperiod. Series 18, 18C, and 13 were terminated on March 29. None of the control (*N*) plants had flowered by June 1, although the same clones then outdoors had done so, as they also did when brought into the greenhouse on April 14 and left on natural daylength. This contrast in plants differently treated on natural daylength is further evidence that exhaustion of carbohydrate reserves may be a factor involved in failure to flower under greenhouse conditions.

Of the August plants, all on 18-hour photoperiod showed marked tiller elongation (figs. 4-6), but no inflorescences were produced. Stem tips of these plants were examined at the close of the experiment on March 29, and all were found to be vegetative.

Tiller counts were made of all plants on January 23 and again on March 26 (table 5). For the August plants, averages of increase in tiller number in the 2 months for the two 18-hour series were lower for each clone than for the 13-hour series. Tiller counts for the December plants showed less correlation with length of photoperiod. This may perhaps be attributed to the shorter time available to these plants for becoming established in the pots before being placed under the lights. Relatively, the *N* series produced most new tillers and the 13-hour series the least.

TABLE 4
NUMBER OF DAYS UNTIL FLOWERING AFTER BE-
GINNING OF PHOTOPERIODIC TREATMENTS
ON JANUARY 7. DECEMBER PLANTS

CLONES	SERIES			
	18	18C	13	<i>N</i>
OM- 1.	23	23	.....	.....
2.	26	26	.....	.....
Cl 9.	21	20	41	.....
23.	26	23	.....	.....
27.	23	23	.....	.....
84.	22	30	.....	.....

Average maximum heights on March 21 for series 18, 18C, 13, and *N*, respectively, were: August plants, 69, 74, 43, and 34 cm.; December plants, 79, 83, 55, and 38 cm. Height was thus greatest in the 18-hour plants and least in the *N* series. December plants were taller than August plants on 18-hour photoperiod, as in most cases the flowering culms overtopped the vegetative tillers of the latter.

Dry weights of tops (table 6) of the August plants were greatest in the 18-hour series; of roots, in the 13-hour series. The plants were cut off at the soil surface, and all below-ground parts were evaluated together as roots with no attempt to distinguish rhizomes and stem bases.

The December plants showed trends similar to those of the August plants in regard to dry weights. Their absolute weights were somewhat greater; since the initial divisions in August and December were approximately equal, this may reflect the failure of the August plants to grow vigorously after being brought into the greenhouse.

Four other clones that were still available, namely, Cl 8, 19, 31, and 65, and a new plant, 914-1, were also brought in during December and were subjected to somewhat similar treatments as the

light was supplied until it was evident that the panicles were mature. Under these conditions, most of the 18-hour plants which had flowered also formed seed which produced vigorous seedlings when planted.

EXPERIMENT III.—An important point in regard to the flowering of brome grass to be determined was the time of initiation of observable floral primordia in the Chicago area. To ascertain this,

TABLE 6
DRY WEIGHTS (GM.) OF PLANTS HARVESTED
MARCH 29. AVERAGES ONLY

PLANTS	18-HOUR		13-HOUR	
	Tops	Roots	Tops	Roots
August.....	8.83	7.49	6.88	8.97
December.....	10.30	9.19	6.09	9.56

TABLE 5
PERCENTAGE INCREASE IN NUMBER OF TILLERS
PER PLANT, JANUARY 23-MARCH 26

PLANTS	SERIES			
	18	18C	13	N
August.....	13.7	36.2	42.8	77.8
December.....	27.7	38.6	27.1	68.6

other six. Results were substantially in agreement. Clone 914-1 was the only plant of this group to bloom on 13-hour photoperiod after 39 days. It also bloomed on the 18-hour photoperiod after 21 days.

Failure to obtain the production of seed in experiment I was a principal reason for repeating the work in a revised form. In 1947, panicles of different clones were shaken together when in anthesis to insure pollination, since the species has a high degree of self-sterility (2). Artificial

stem tips of plants of the eleven clones still in the garden in 1947 were dissected out periodically during the spring after growth had been resumed. Floral primordia were first discovered on Cl 9 on April 8, on OM-1, Cl 27, Cl 84, and 914-1 on April 9, on Cl 23 on April 10, and on OM-2 on April 14. In all cases the reproductive growing points were located at or near the ground level in unelongated shoots 20 cm. or more in height. The spring of 1947 was abnormally cold, and these dates may be considerably later than the average time of initiation.

To determine to some extent the conditions necessary for the further development and elongation of the inflorescences, plants of these seven clones were brought in on April 14, potted, and put on 13-hour photoperiod, receiving 9 hours of natural daylight in the open greenhouse and 4 hours of supplementary light supplied by three 30-watt fluores-



FIGS. 4, 5.—Clonal divisions of smooth brome grass grown after January 6, 1947, on photoperiods of 13 hours (*left pair*) and 18 hours (*right pair*). Left-hand plant of each pair was brought into greenhouse on August 31, 1946; right-hand plant of each pair, on December 27. Fig. 4, OM-1; fig. 5, OM-2. Initial clonal divisions were much larger than for plants shown in figs. 1-3. (Photographed March 28, 1947.)

cent lamps in the shed. On the basis of the samples dissected, the majority of the larger tillers on all clones were then in the reproductive state. By May 12 clone 914-1 had produced several very depauperate inflorescences, and, by May 18, OM-1, Cl 9, and Cl 84 had produced completely barren elongated culms. On June 3 the remaining plants of this group

that none of the tillers on the section brought in were reproductive on April 14.

These observations are in contrast to the behavior of divisions of clones Cl 23 and 914-1 also brought into the greenhouse on April 14 and allowed to grow under the increasing natural photoperiods. Tillers of these, dissected on April



FIG. 6.—As in figs. 4, 5. Cl 9

on 13-hour photoperiod were examined by dissection. Cl 23 had several tillers with panicles well developed and nearing exertion, but the branchlets of the panicles were brown and withered except for the lowermost two or three, which were still green. About six internodes had elongated in each tiller examined. Cl 27 was in a similar condition but with inflorescences less developed. OM-2 showed only vegetative stem tips. This was a very small plant because of a lack of material in the garden, and it is possible

23, were found to have inflorescences up to 11 mm. long with branches well developed. One plant flowered on May 2, with normal panicles, and all were in bloom by May 14. This is in sharp contrast to the failure of the *N* series of experiment II to flower on the even longer photoperiods of late May and early June. It is possible that the *N* plants required a longer period of chilling in order to flower, comparable to that received by the plants brought in on April 14. It is more probable, however, that the subjec-

tion of the December *N* series to the adverse effects of 3 months of dark and short but relatively warm winter days in the greenhouse was more significant than the amount of chilling, in view of the excellent flowering of the December plants on 18-hour photoperiod after the same amount of chilling. The failure of the August plants to flower on 18-hour photoperiod may also be attributed partly to the adverse effects of too long a period in the greenhouse in small pots with short photoperiods and low light intensity.

Discussion

The pronounced effect of the longer photoperiods in promoting culm elongation and, under some conditions, the production of panicles in brome grass is in agreement with the results of most other investigators. The differences in the amount of flowering and in the time required for flowering between the plants on long photoperiods and those on natural daylength in winter were marked.

That the effect of long photoperiods is not primarily or perhaps not at all responsible for the initiation of inflorescences is indicated. Attainment of the physiological condition resulting in the formation of floral initials as the first morphological sign of the reproductive state is with little doubt caused by a complex of factors. The interrelations of temperature with photoperiod have been examined for a number of species of plants (10, 15). In the case of sugar beets, it has been found difficult to distinguish the roles of the two factors, and induction of flowers under the influence of prolonged low temperatures and long photoperiods is tentatively regarded as a single process (9). In brome grass the importance of chilling in the process is probably marked in many individuals in the

species, even though in the clonal material used by EVANS and WILSIE (3) some of the plants brought in during October flowered well under certain conditions. The degree of chilling to which they had been subjected was unspecified. The need for chilling for floral initiation has been reported for other species of grasses. Some unspecified American work on cocksfoot is reported by WHYTE (15). Plants grown for 6 months under a 16-hour photoperiod in a greenhouse produced no heads; preconditioning by growing on short photoperiods and low temperature for 2-3 months resulted in flowering after removal to the 16-hour day. WHYTE also reported (15) that a late-flowering strain of perennial ryegrass was induced to flower early after exposure to winter conditions in Wales followed by transfer to continuous light plus higher temperatures.

Pre-chilling, however, is not invariably essential to flowering in brome grass. On July 1, 1946, seven clones were observed in anthesis in the greenhouse, including three used in the present work—Cl 9, 65, and 84. These plants had been in the warm greenhouse since June, 1945. This plant of Cl 9, still in the greenhouse, flowered again in 1947, on June 20. The August plant of the same clone in the *N* series of experiment II also was in flower on June 20. The internal balance or possible specific substances necessary to cause the change from the vegetative to the reproductive state apparently can be reached or formed through more than one complex of causes, in which temperature, light, age of plant, nutrition, genetic factors, and others, may be operative at various levels to produce the same end result.

The fact that floral primordia are formed by early April on brome grass in the field at Chicago indicates that a long

photoperiod is not required for initiation during the season of flowering, whatever may be its role in the previous season. KNOBLOCH (6) observed that on May 1 at Ames, Iowa, inflorescences are found near the ground level and are 1-1.5 cm. long. He stated that panicle primordia are initiated only in the year of anthesis. In northern Ohio the growing points of many perennial grasses remain vegetative during late summer and fall; floral primordia become visible in April or very early in May of the following year (4). WHYTE (15) concluded that it appears in England that "although grasses such as cocksfoot and ryegrass may be ripe-to-flower during the winter months (with no external evidence of this condition), the flower primordia are not laid down until March of the following year."

Long day, then, if it is an essential factor in floral initiation in brome grass, must apparently affect the plant in one growing season and the physiological effect be carried over to the next. It is not difficult to agree with SHARMAN, as quoted by WHYTE (15), who doubted whether daylength is of importance in the change from the vegetative to the reproductive state in perennial grasses such as ryegrass or sweet vernal.

Normal development and elongation of the culms and of the panicle initials, on the other hand, seem, in brome grass, to be definitely related to certain photoperiods. This is evidenced both by its flowering on natural daylength as the season advances and by the experimental results. It is significant that the clones referred to above as flowering without pre-chilling did so only after the days had lengthened, though temperature conditions did not preclude flowering at any time of year. Also, when plants with floral primordia already present were placed on 13-hour photoperiods, exser-

tion of the inflorescences was effectively inhibited in three clones, with only barren or depauperate panicles produced in the four others tested. The degenerating state of the inhibited inflorescences was similar to that described by TINCKER (11), who found that plants of early timothy on 6-, 9-, and 12-hour photoperiods all produced tillers containing young flowers checked in development and dying off. Sweet-scented vernal grass, prevented from flowering by 6-hour photoperiod, had floral primordia consisting of minute outer glumes inclosing a group of meristematic cells. In the Gramineae in general, he concluded, it is possible for the primordia (rachis and glumes) to be laid down and development arrested at such a stage (12).

Two clones of brome grass, OM-1 and Cl 23, flowered only on short photoperiod in experiment I and only on long photoperiod in experiment II. Since, however, they flowered 45 and 30 days earlier, respectively, on long photoperiod than on short, it is reasonable to assume that the longer photoperiod is more favorable for the completion of reproductive activity. The fact that both OM-2 and Cl 84 flowered on 18-hour photoperiod in 1947 and failed to flower on a 17-hour photoperiod in 1946 could be interpreted to mean that the lower critical limit for flowering of these clones lies between 17 and 18 hours. However, it is perhaps more reasonable to believe that the large pieces of clonal material used in 1947 were more representative of the state of the entire plant at the time of bringing it in than were the single pieces of rhizome used in 1946. Growing-points of the segments used in 1946 may not have been "ripe-to-flower" because of age, position on the plant, or other factor.

Vegetative behavior under the conditions of these experiments was consistent

with that reported by others for brome grass (1, 3, 14) and for other species of grasses (1, 8, 11, 15). Plants on short photoperiods tillered more abundantly than those on long photoperiods and showed little stem elongation. Shoots produced on short photoperiod were generally decumbent or semi-decumbent, resulting in a rosette type of plant. On 18-hour photoperiod marked elongation of sterile shoots occurred in the August plants of experiment II, so that at harvest the plants closely resembled the types called "sterilclinous" by WALDRON (13). This also occurred in the 18-hour December plants in two or three instances (fig. 6) in which sterile shoots continued growth after maturation of the panicles on other culms and finally overtopped the flowering stems.

Growth and flowering responses of brome grass in these experiments showed no apparent correlation with place of origin of the clones. Differences of a few days in time of flowering cannot be held significant when the approximate nature of the data is considered. The thirteen clones behaved in a somewhat similar manner physiologically under the experimental conditions, in spite of their diversity in origin and habit, with the possible exception of the Manchurian clone, Cl 9. This plant was consistently the first to flower on long photoperiods and bloomed also on 15- and 13-hour light periods. It has flowered as well without preconditioning by chilling. Vegetatively it was the tallest of the clones and produced the greatest weight of both tops and roots.

It is apparent that a combination of conditions is necessary to insure most vigorous growth, flowering, and production of seed of brome grass in the greenhouse in winter. In these experiments these ends were accomplished most successfully when the plants were brought

in from the field after a period of chilling and were allowed to grow in the pots for only 10 days before being subjected to a relatively high intensity of supplementary light and long photoperiods. Fairly large pieces of transplant material were more successful than single rhizomes.

Summary

1. Flowering and growth responses of thirteen diverse clones of smooth brome grass were studied in greenhouse experiments, supplemented by observations made on plants established in the field, conducted during the winter and spring of 1946 and 1947.

2. In early 1946, clonal divisions, consisting of single sections of rhizomes, were grown on Chicago natural daylength and light intensity and on 17-, 15-, and 13-hour photoperiods under fluorescent lamps providing relatively high light intensity and under incandescent-filament lamps providing relatively low light intensity. Flowering first occurred approximately 1 month after bringing the plants in from the field in early January. Earliest and most prolific flowering and most vigorous vegetative growth occurred on 17-hour photoperiod under fluorescent light. The number of elongated tillers was directly, and of unelongated tillers inversely, correlated with length of photoperiod. Rhizome production was not obviously affected by photoperiod but was strongly affected by light intensity.

3. Plants were brought in from the field on August 31, 1946, and again on December 27 after exposure to low temperatures. Clonal divisions of both groups of plants, consisting of pieces of entire plants, were grown on 18- and 13-hour photoperiods under fluorescent lamps, beginning January 7, 1947, and on natural daylength. Flowering of the 18-hour De-

ember plants occurred in approximately 3-4 weeks after differential photoperiodic treatments were begun. One December plant on 13-hour photoperiod flowered. No December plants on natural daylength had flowered by June 1. None of the August plants flowered under any treatment, but all on long photoperiod showed marked tiller elongation. Increase in number of tillers was greatest for the August plants on natural daylength, least for those on 18-hour photoperiod. Of the December plants, the series on natural daylength produced most new tillers, plants on 13-hour photoperiod least. Dry weights of tops of both August and December plants were greatest in the 18-hour series, of roots in the 13-hour series. Height in both August and December plants was greatest in the 18-hour series, least in the series on natu-

ral daylength. Fully viable seed was produced on the 18-hour December plants under the relatively poor growing conditions of a Chicago winter in the greenhouse.

4. Floral primordia were present on plants growing in the field at Chicago in early April. A 13-hour photoperiod inhibited their subsequent normal development and elongation.

5. The vegetative and flowering responses showed no apparent correlation with place of origin of the clones.

The writer wishes to thank Dr. CHARLES E. OLMSTED for his interest and assistance throughout the course of this work, and Dr. ETLAR L. NIELSEN for furnishing the clonal material used.

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